Elena Surovyatkina

*Potsdam Institute for Climate Impact Research (PIK)*

# New approach pushes limits of numerical weather prediction

Federal Ministry
for the Environment, Nature Conservation
and Nuclear Safety
B-EPICC project
18_II_149_Global_A_Risikovorhersage

INTERNATIONALE
KLIMASCHUTZINITIATIVE (IKI)



16 August, 2022, Lima, Peru

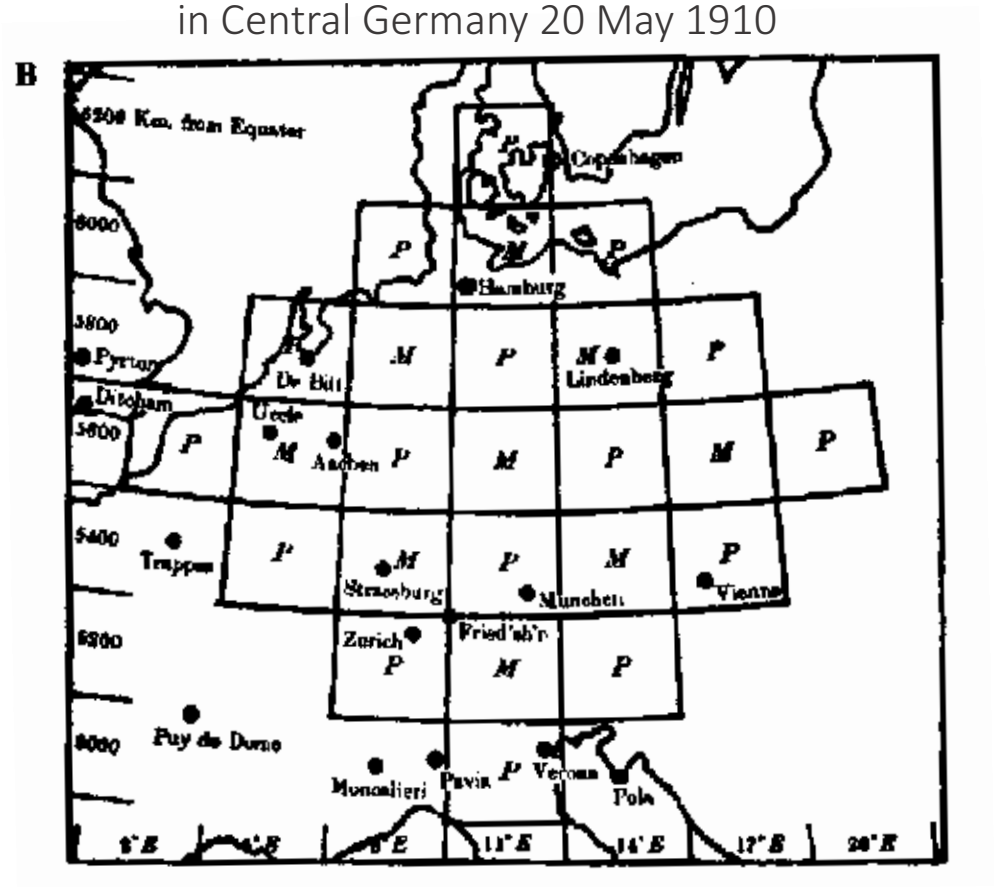
# Contents

- Major limitations in numerical weather prediction
- The main principles of the prediction of monsoon timing
- Future perspective for the extension of monsoon forecast worldwide.

‘‘Perhaps someday in the dim future, it will be possible to advance the computations faster than the weather advances. … But that is a dream.“ 1922

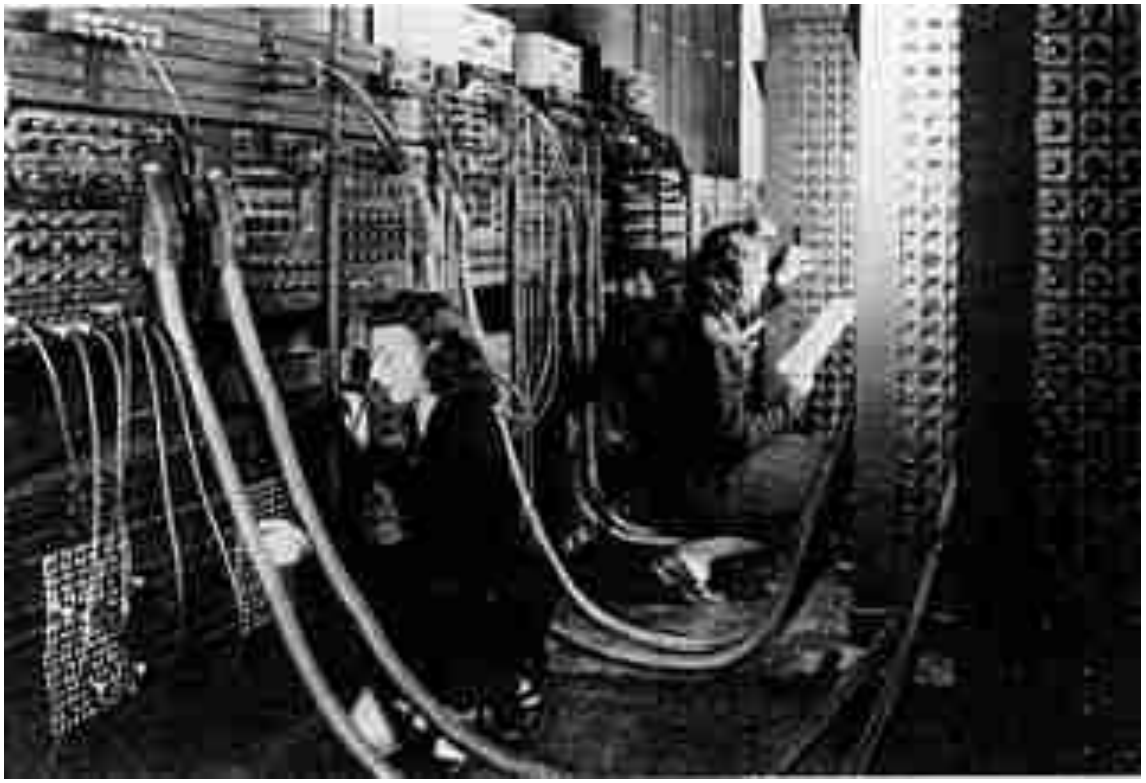
Lewis Fry Richardson
11 October 1881 – 30 September 1953

A six-hour weather forecast for two points in Central Germany 20 May 1910




Richardson, L.F.: Weather Prediction by Numerical Process. Cambridge University Press, Cambridge (1922)

# The first calculations for a 24-hour forecast took ENIAC nearly 24 hours to produce (1950)



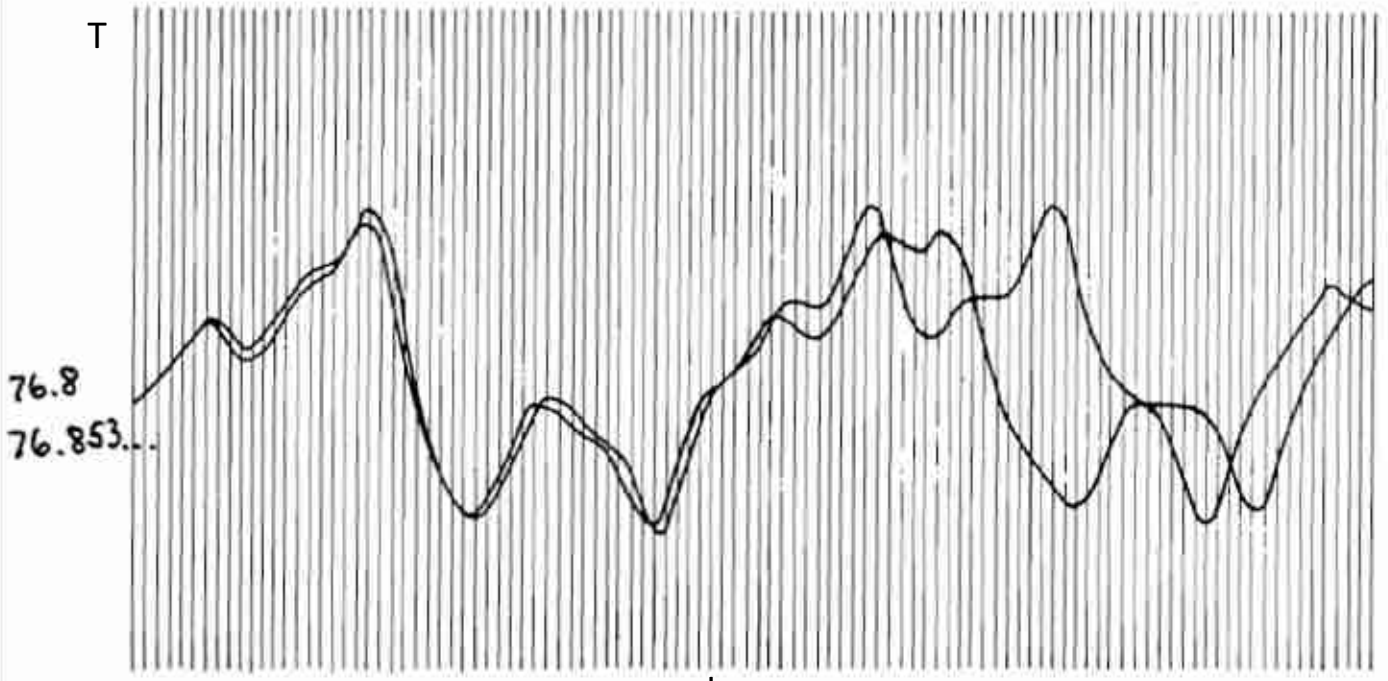
ENIAC Programmers, 1943-1945:
*Gloria Ruth Gordon [Bolotsky] and Ester Gerston*

A group of female "computers" was instrumental in building the ENIAC during World War II.

# Butterfly effect: “When a butterfly flutters its wings in one part of the world, it can eventually cause a hurricane in another.”

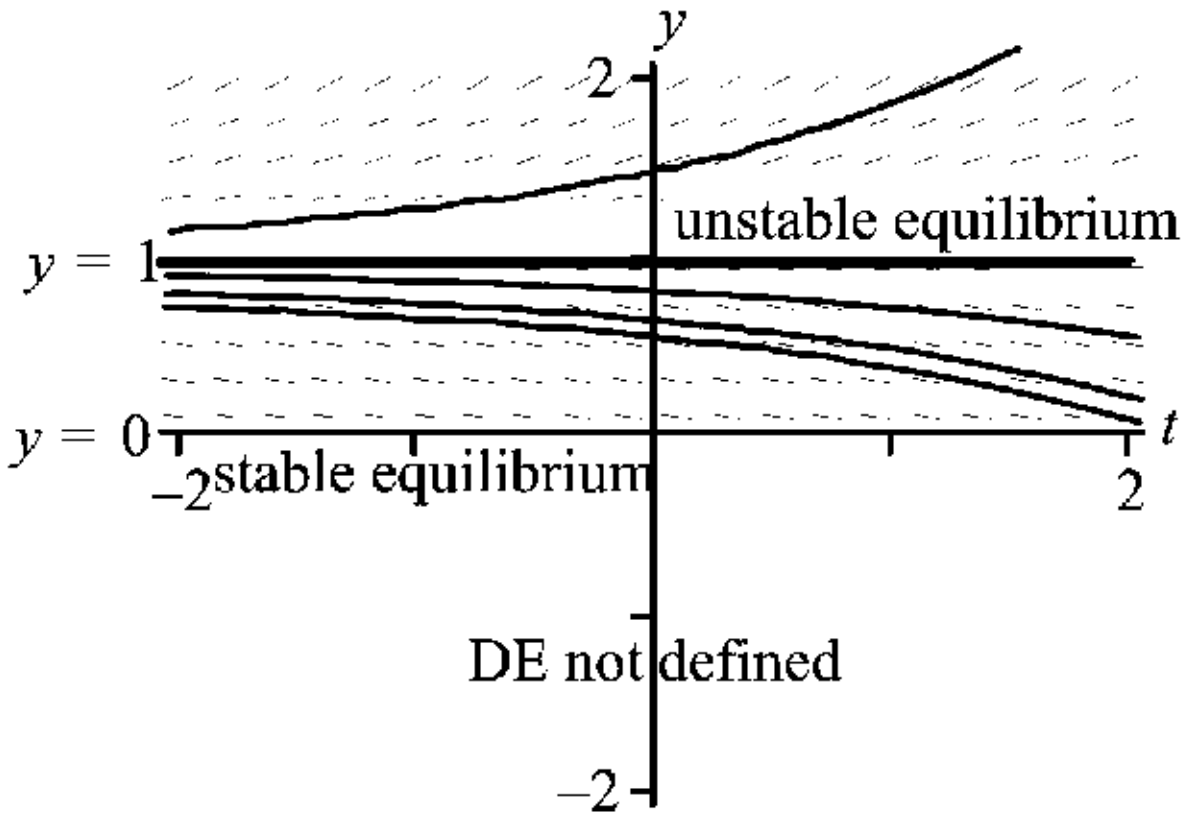
Edward Norton Lorenz
May 23, 1917 – April 16, 2008

A small change in initial conditions had created a significantly different outcome.




HOW TWO WEATHER PATTERNS DIVERGE. From nearly the same starting point, Edward Lorenz saw his computer weather produce patterns that grew farther and farther apart until all resemblance disappeared. (From Lorenz's 1961 printouts.)

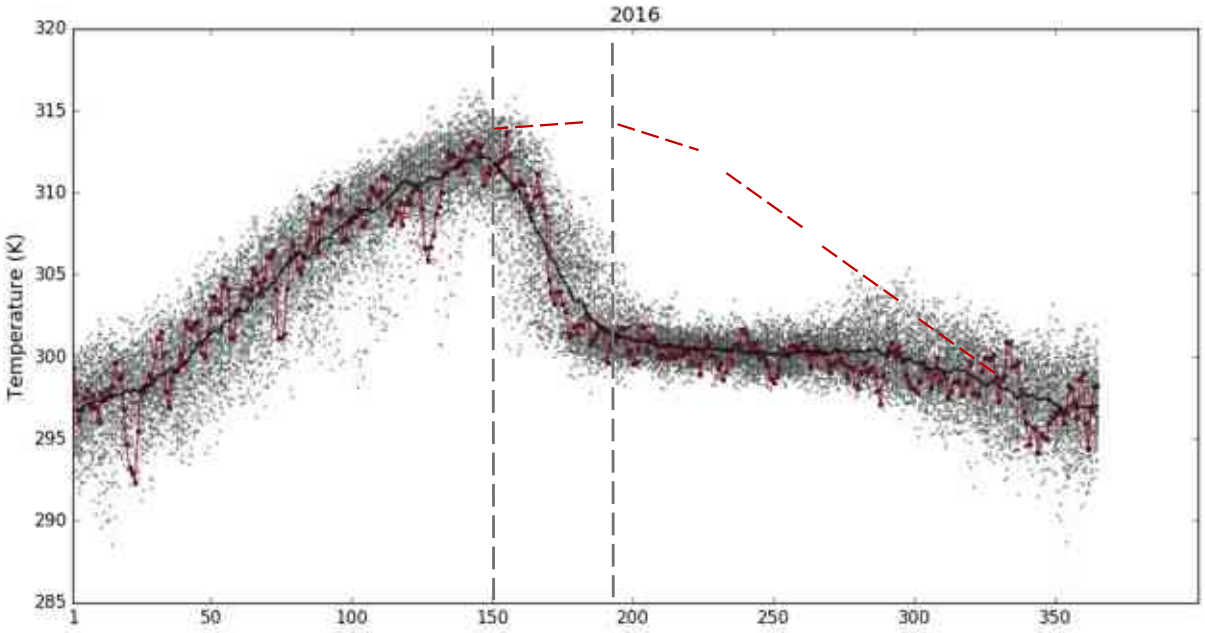
# Unstable solution



# A fundamental problem in numerical weather prediction

A fundamental problem lies in the chaotic nature of the spatial differential equations used to simulate the atmosphere. It is impossible to solve these equations exactly, and **extremely small errors in temperature, wind, or other initial inputs grow with time - double every five days**,[Cox, John D., 2002] making it **impossible for long-range forecasts.** Therefore, numerical weather prediction methods only obtain an approximate solution.

# Abrupt transition




Daily mean near-surface air temperature over the Eastern Ghats (1950-2020)

The numerical weather model **cannot reproduce the abrupt transition** common in the tropics.

# Major limitations in numerical weather prediction

- Numerical Weather Prediction has a limit to forecast the weather for **up to 5 days** in the future.
- Existing observation networks have poor coverage in some regions (for example, over the Pacific Ocean), which introduces uncertainty into the true initial state of the atmosphere. These uncertainties limit forecast model accuracy to about **five or six days** into the future [Weickmann et al. 2001], [Chakraborty, Arindam, 2010 ].
- General Circulation Model (GCM) includes an inadequate description of basic processes like **cloud formation, moist convection, and mixing** is what climate models **miss most** [Stevens and Bony, 2013].
- «Use of high-resolution regional models to downscale **regional climate change** is questionable if the global models from which **lateral boundary conditions** are prescribed are **not realistic**»[J.Shukla at al, 2009]

- **The limitations of current models prevent further progress**. A new strategy is desperately needed in weather and climate sciences [Stevens and Bony, Science 31 May 2013]

Once we accept our limits, we go beyond them.

Albert Einstein

# Tipping Elements approach

The approach is fundamentally different from the numerical weather forecast; it is based on new spatial-temporal regularities (or teleconnection between Tipping Elements) and data analysis.

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2016GL068392

**Key Points:**
- We identify geographic regions of critical behavior as tipping elements
- We use critical fluctuations in air temperature as a precursor of monsoon timing
- We improve the time scale of monsoon onset and withdrawal forecasting

**Supporting Information:**
- Supporting Information S1

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veronika.stolbova@pik-potsdam.de

# Tipping elements of the Indian monsoon: Prediction of onset and withdrawal

**Veronika Stolbova[1,2,3,4], Elena Surovyatkina[1,5], Bodo Bookhagen[6,7], and Jürgen Kurths[1,2,3,8]**

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**Abstract** Forecasting the onset and withdrawal of the Indian summer monsoon is crucial for the life and prosperity of more than one billion inhabitants of the Indian subcontinent. However, accurate prediction of monsoon timing remains a challenge, despite numerous efforts. Here we present a method for prediction of monsoon timing based on a critical transition precursor. We identify geographic regions—tipping elements of the monsoon—and use them as observation locations for predicting onset and withdrawal dates. Unlike

# What does the term 'tipping' mean?

One of the definitions of tip

- *overbalance or*
- *cause to overbalance*

*"The hay caught fire when the candle tipped over….."*

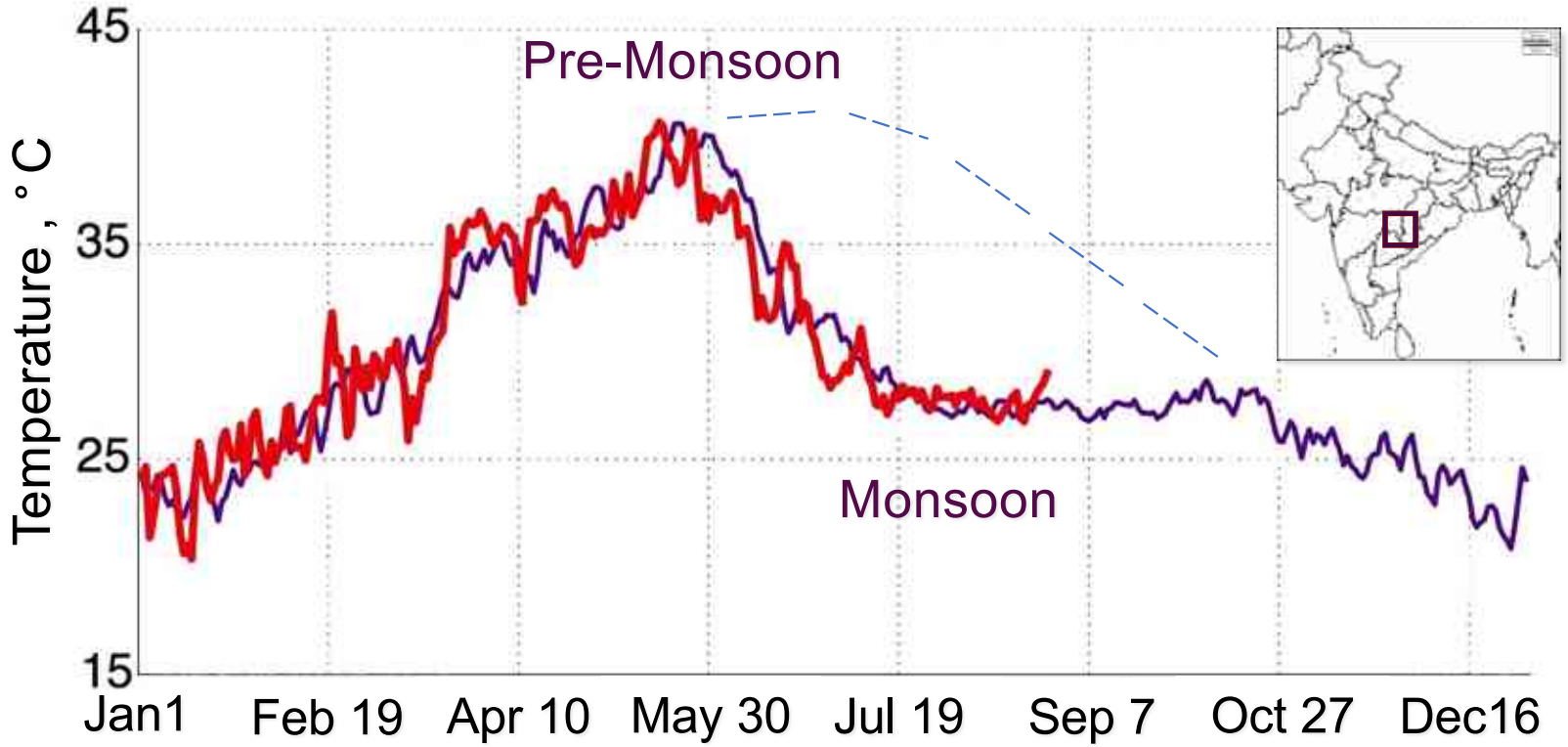
- ✓ The candle is an origin of the problem – *a tipping element of the system*.
- ✓ The time when the candle tipped over is *a tipping point*.
- ✓ An open window which gives the direction of flame propagation is the second *tipping element of the system*.

«The onset of monsoon... Is not a transition from a regime of no rain to rain; it is a transition from a regime of sporadic rainfall to spatially organized and temporally sustained rainfall...»

critical

R. Ananthakrishnan and M.K. Soman, 1990

Is it  a critical transition from pre-monsoon to monsoon?



- Where (geographically) do the critical conditions originate?
- How do the critical conditions propagate in space?
- How to predict a future transition?

# DATA


**NCEP/NCAR Reanalysis 1**

•4-times daily, daily and monthly values for 1948/01/01 to present
•2.5 degree latitude x 2.5 degree longitude global grid (144x73)

https://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.surface.html

**ERA-Interim**

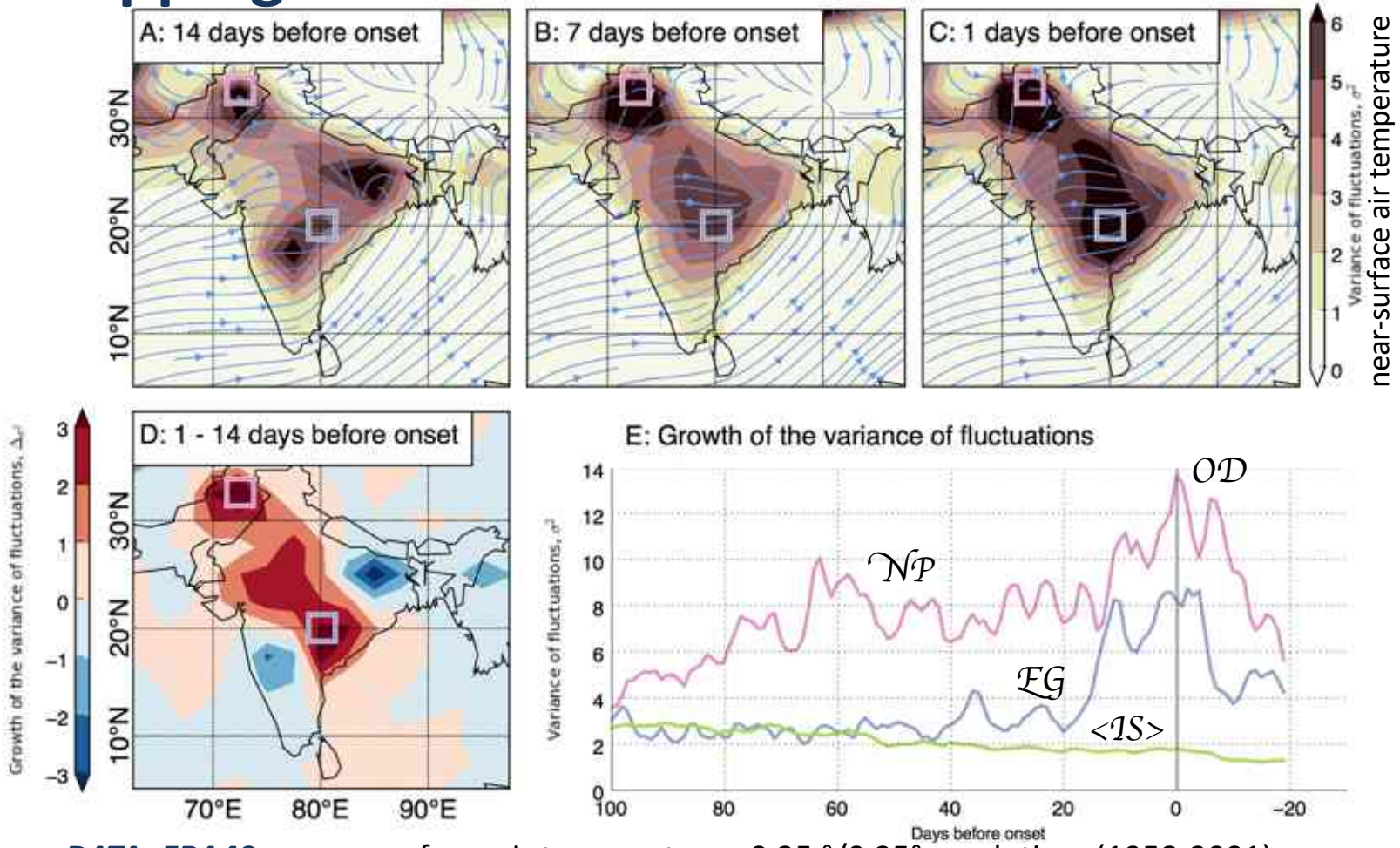
•4-times daily, daily and monthly values for 1979/01/01 to present (delay 2m)
•0.125 degree latitude x 0.125 degree longitude global grid

https://www.ecmwf.int/en/forecasts/datasets/archive-datasets/reanalysis-datasets/era-interim

# The Indian Summer Monsoon

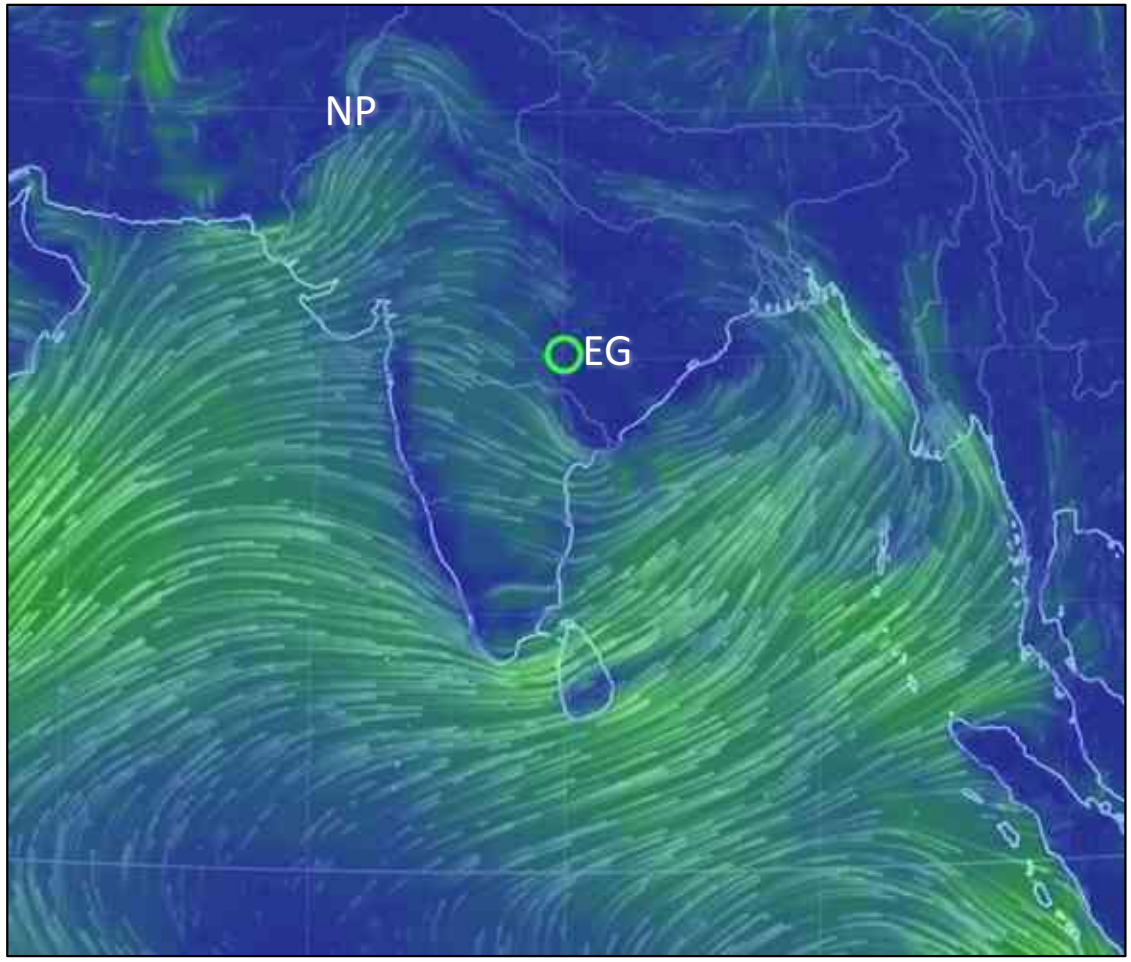
1. Where (geographically) do critical conditions originate?

# Tipping elements of Indian Summer Monsoon




***DATA: ERA40***: near –surface air temperature, 0.25 °/0.25° resolution, (1958-2001)

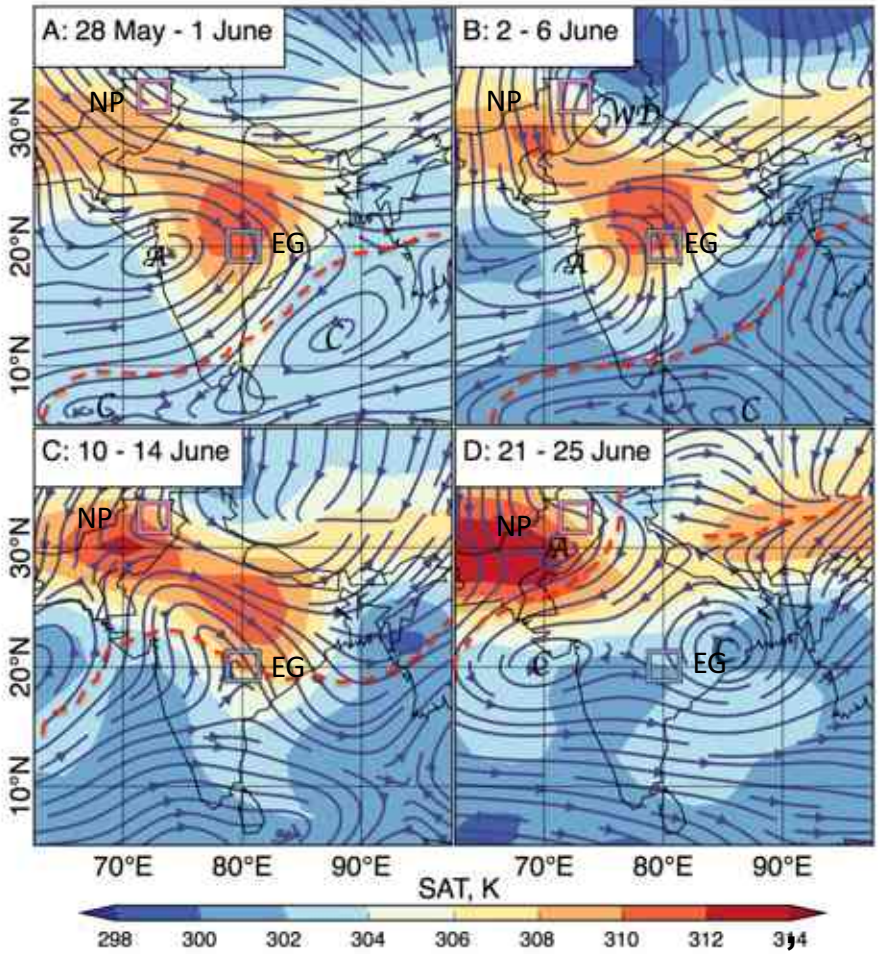
# 2. How do the critical conditions propagate in space?




https://earth.nullschool.net/#2016/06/17/0300Z/wind/isobaric/1000hPa/orthographic=78.74,8.05,626/loc=80,20

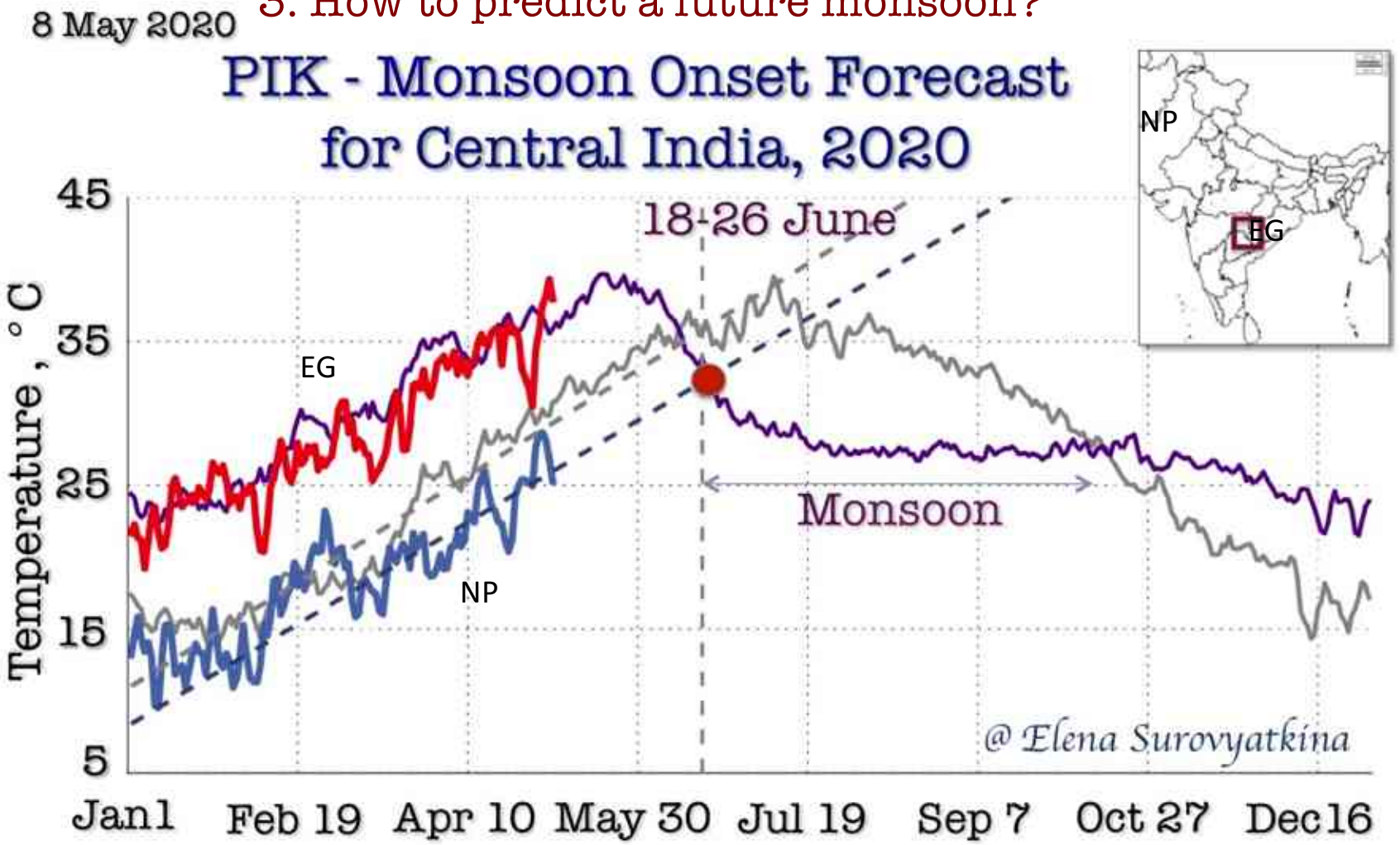
The onset of monsoon in the EG appears when the conditions in two regions NP and EG equalizes.

Temperature & wind fields

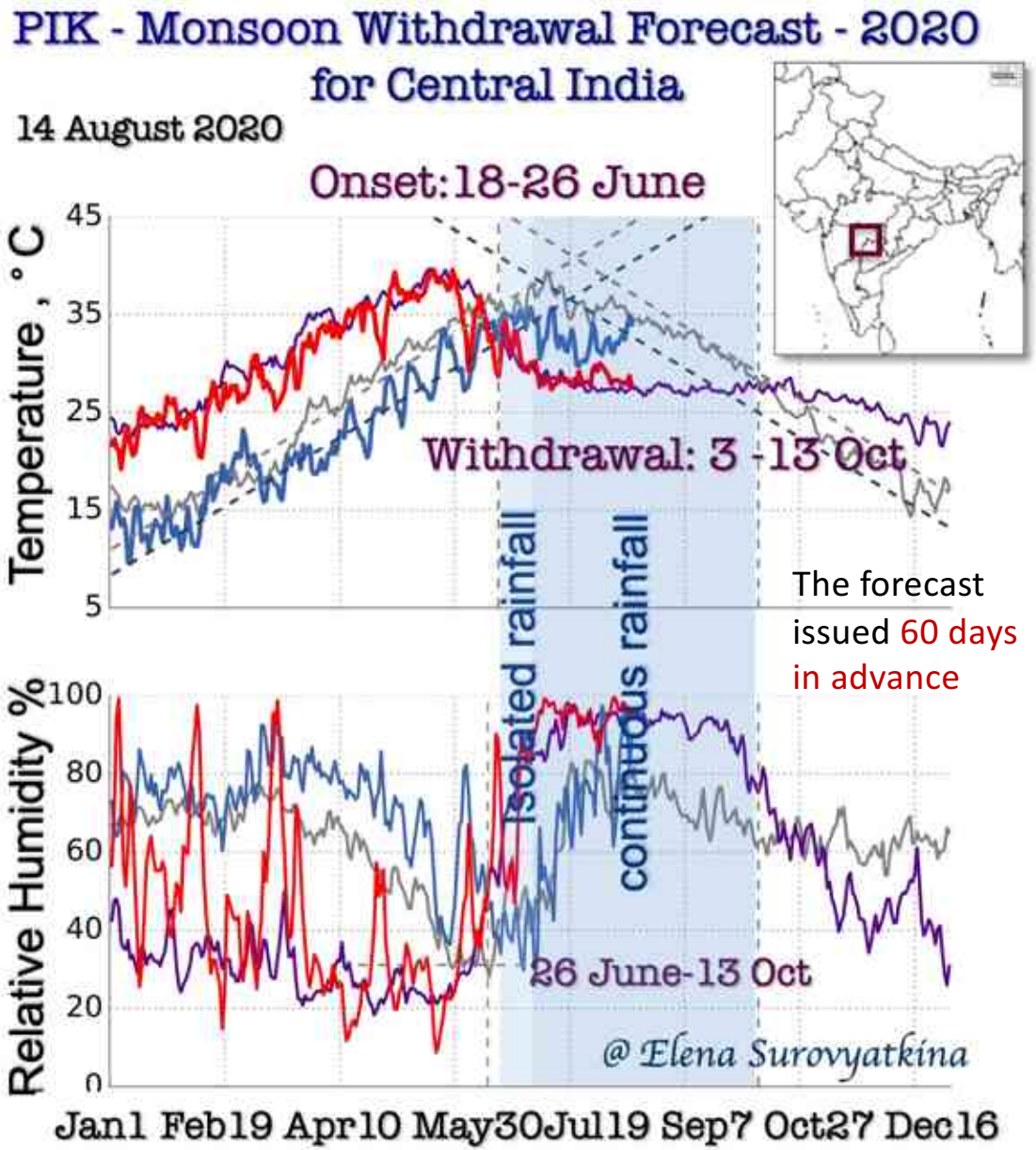



DATA: NCEP/NCAR reanalysis, 2.5°, near –surface air temperature, (1951-2015)

# 3. How to predict a future monsoon?




Daily mean near-surface air temperature till **May 8, 2020**, for the Eastern Ghats (red) and North Pakistan (blue). Violet and gray lines- past 5-years average for same regions. The tipping point (red) indicates the critical temperature and the forecasted onset date. The forecast issued 40 days in advance




Summer Monsoon 2020 in Central India began on the 26th of June.

The Indian Summer Monsoon (Southwest Monsoon) is likely to withdraw from the Central part of India (20N, 80E) between 3rd and 13th of October 2020.

Temperature anomaly in North Pakistan shrinks the duration of the monsoon season.

Nevertheless, after the monsoon withdrawal date in October, others post-monsoon rainfalls might appear over the central & northwest India.

# INDIAN SUMMER MONSOON FORECASTS (Central India, Eastern Ghats)

| | ONSET OF MONSOON | | WITHDRAWAL OF MONSOON | |
|---|---|---|---|---|
| Year | FORECAST 40 DAYS IN ADVANCE | OBSERVATION | FORECAST 70 DAYS IN ADVANCE | OBSERVATION |
| 2016 | 9-17 June | 17 June | 1-10 October | 10-12 October |
| 2017 | 14-22 June | 16-18 June | 7-17 October | 15-16 October |
| 2018 | 11-19 June | 9-19 June | 13-23 October | 18-21 October |
| 2019 | 10-18 June | 18-19 June | 14-24 October | 14-24 October |
| 2020 | 18-26 June | 26 June | 3-13 October | 7-13 October |
| 2021 | 21-29 June | 29 June | 31-10 October | 8-10 October |

https://www.pik-potsdam.de/en/output/infodesk/forecasting-indian-monsoon/welcome-to-the-pik-monsoon-page-1

# The South American Monsoon

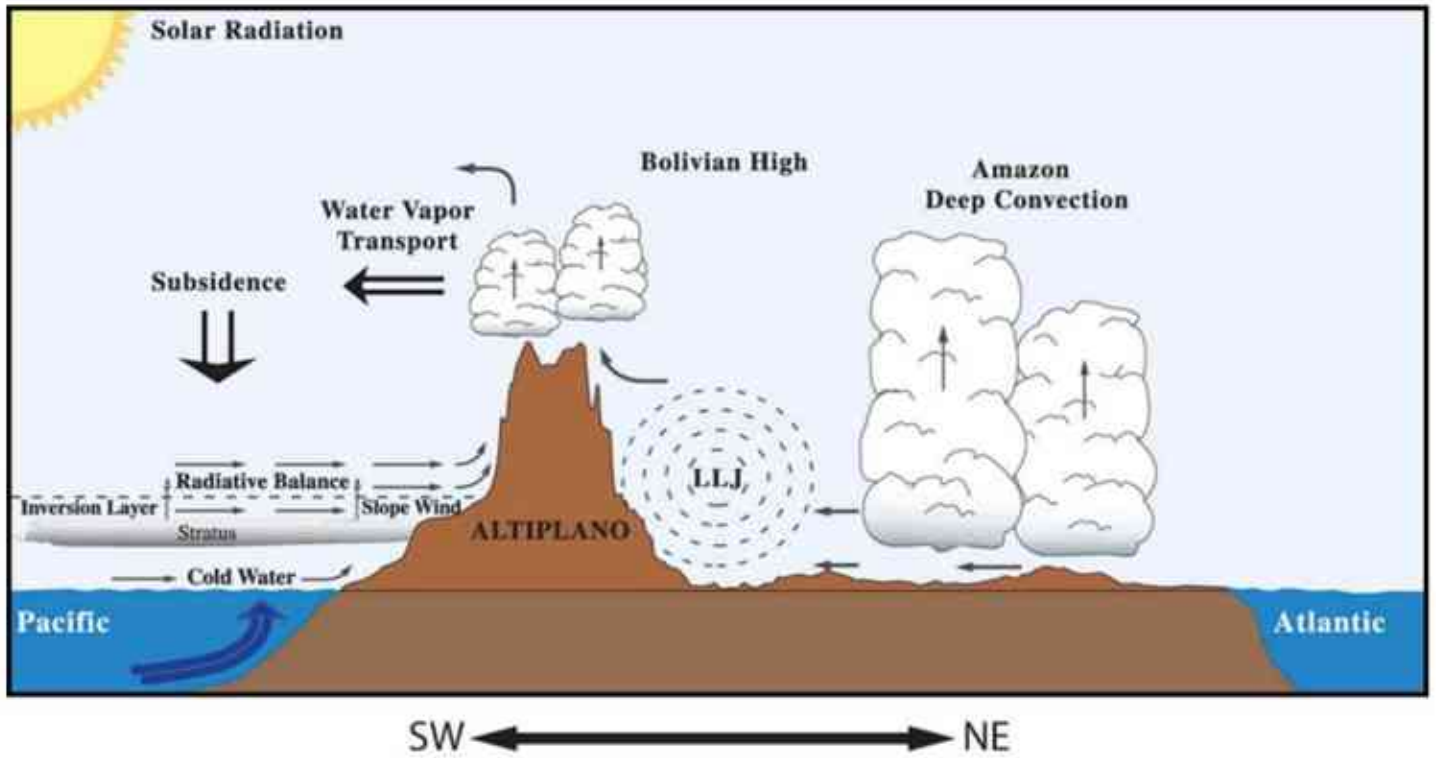



Fig. 4. Section across South America displaying schematically the major large-scale elements related to the South American Monsoon System. Source: Climate Variability & Predictability Program (CLIVAR)
(http://www.clivar.com/publications/other_pubs/clivar_transp/pdf_files/av_g3_0106.pdf)

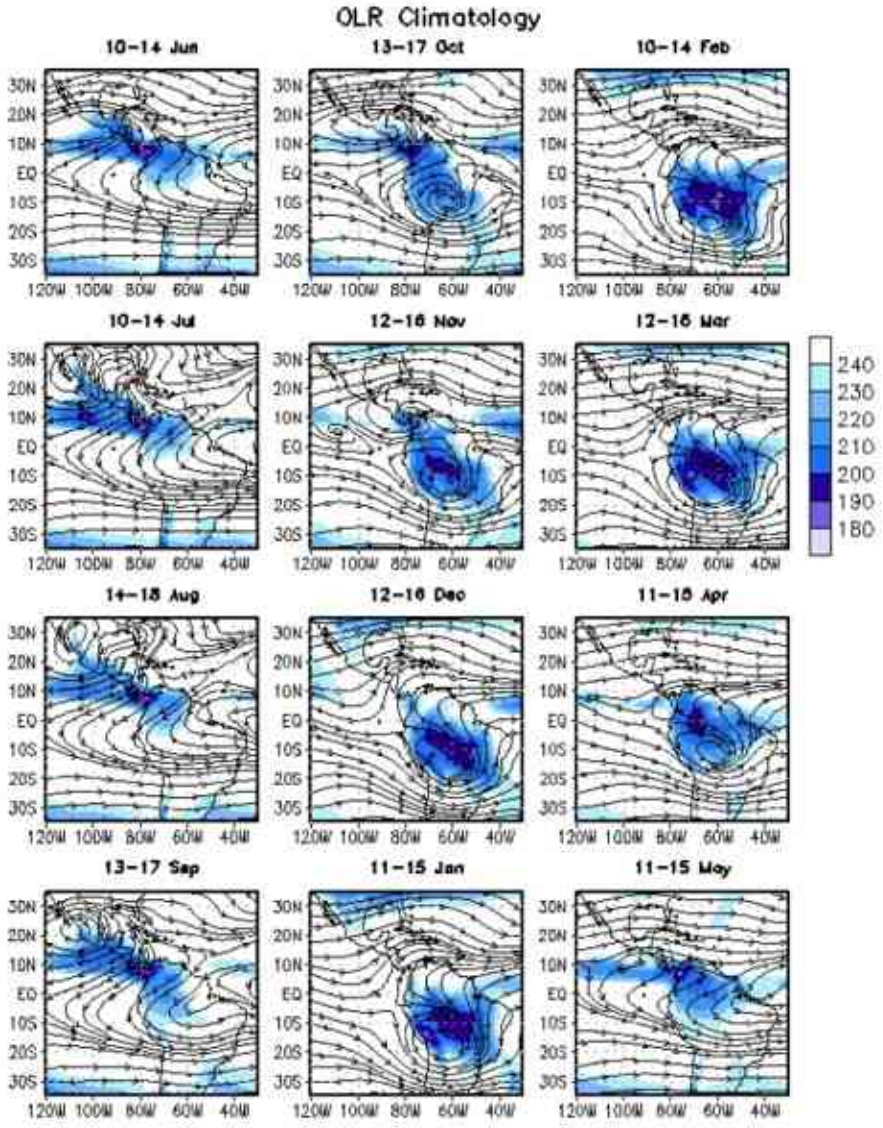



Fig. 8. Mean (1979-1995) seasonal cycle of OLR and 200-hPa streamlines. Units for OLR are W m$^{-2}$. Low values of OLR indicate cold cloud tops (deep convection) in the Tropics.

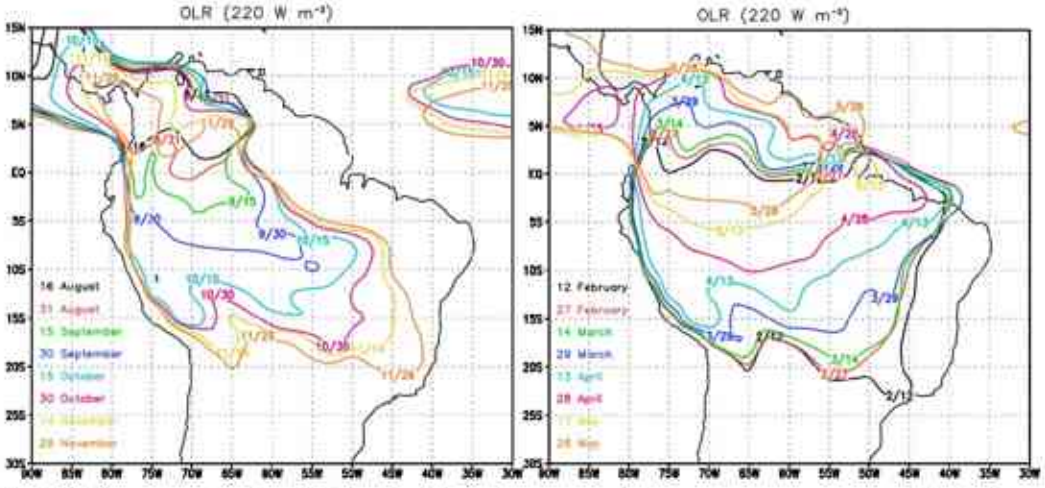
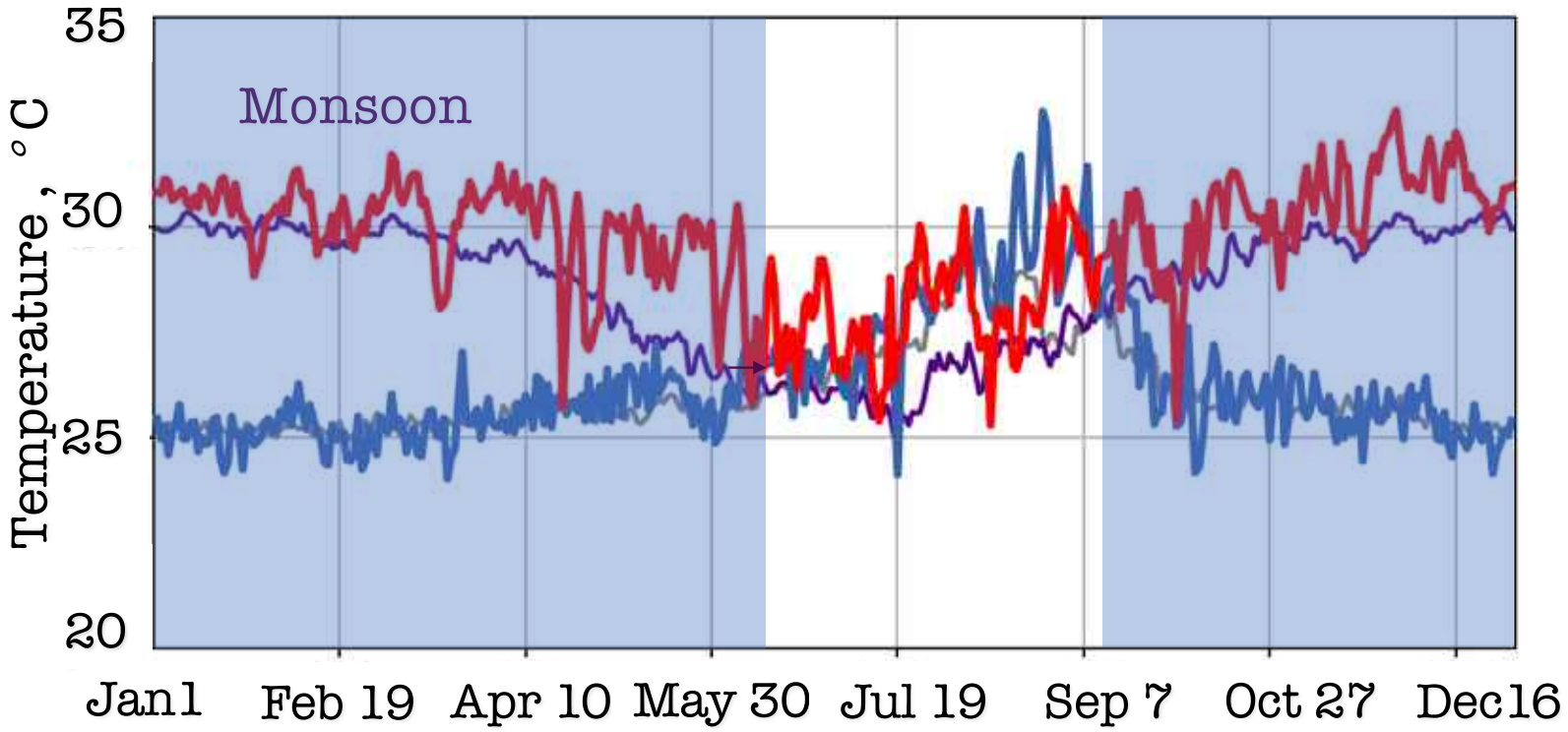



Fig. 10. Time onset and end dates for the wet season in the monsoon core region (Central Brazil) based on OLR less than 220 W m$^{-2}$.

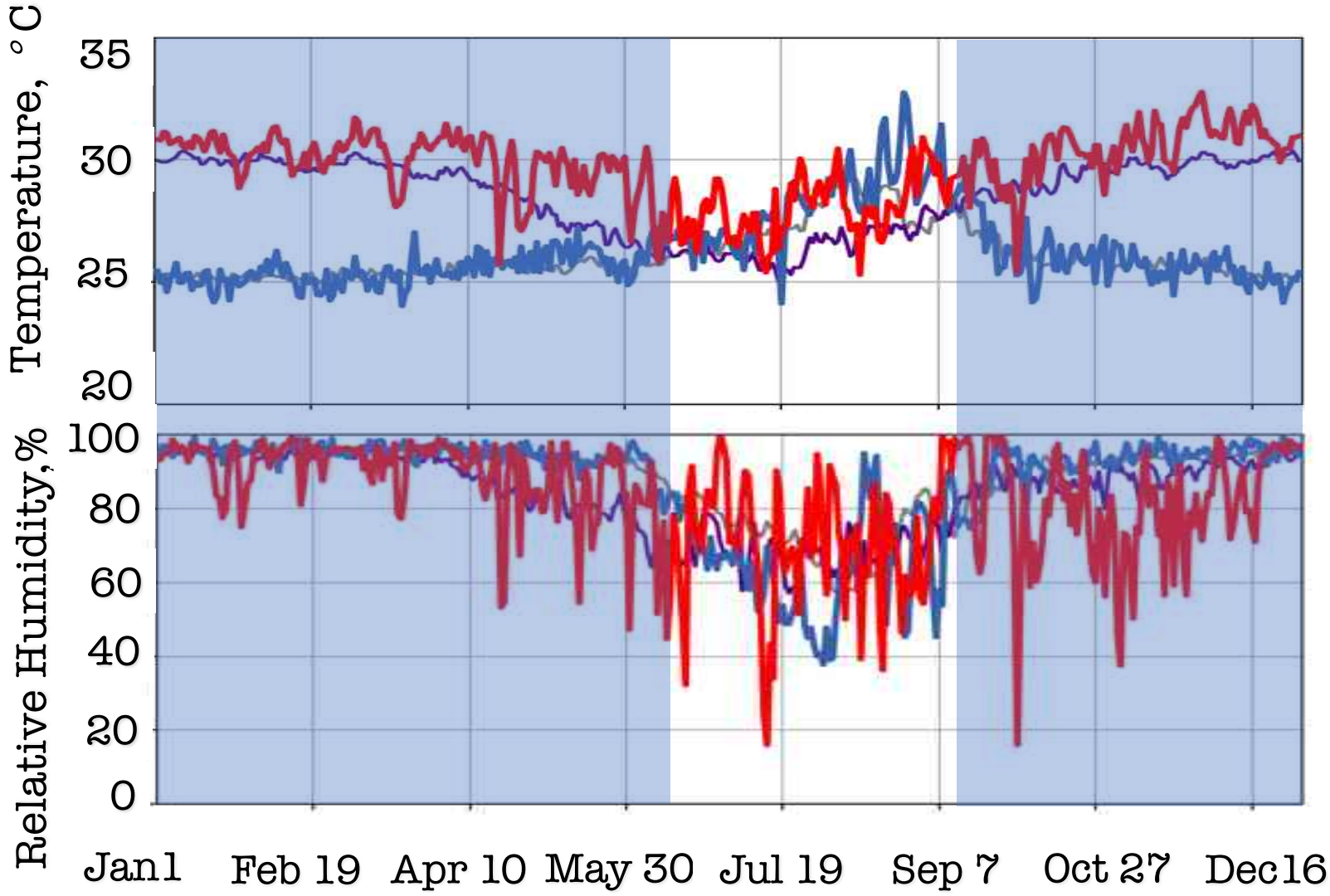
Vernon E. Kousky,; Viviane B. S. Silva,. The South American Monsoon System: Climatology and Variability. INTECH Open Access Publisher, 2012. Edition/Format: eBook

# South American Monsoon, Brazil, 2017



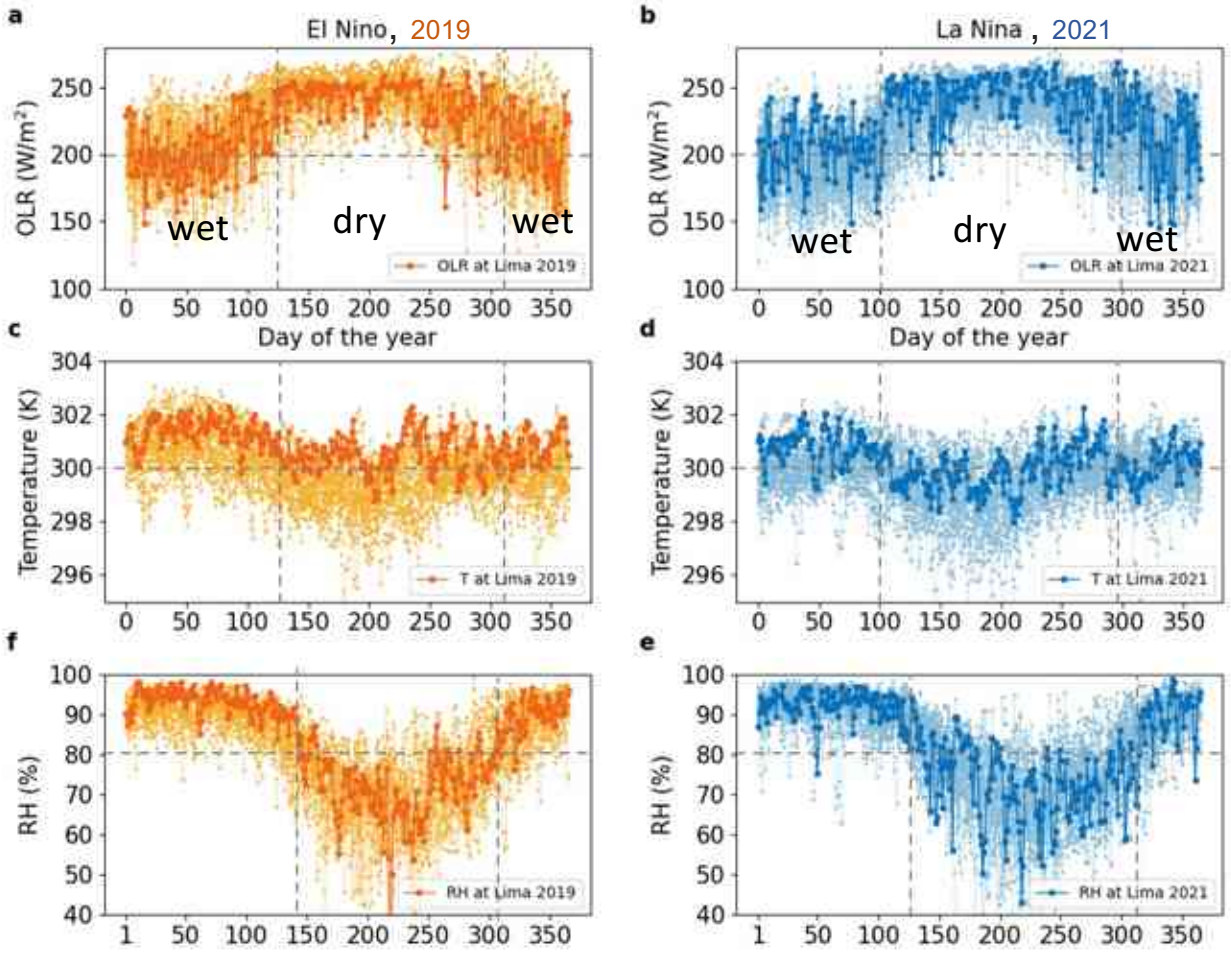

Daily mean near-surface air temperature **2017**, for two region in Brazil in Southeast (red) and Northwest (blue). Violet and gray lines- past 5-years average for same regions. The intersection indicates the critical temperatures of the beginning and end dates.

# South American Monsoon, Brazil,2017



Distrito de Izcuchaca (Huancavelica)

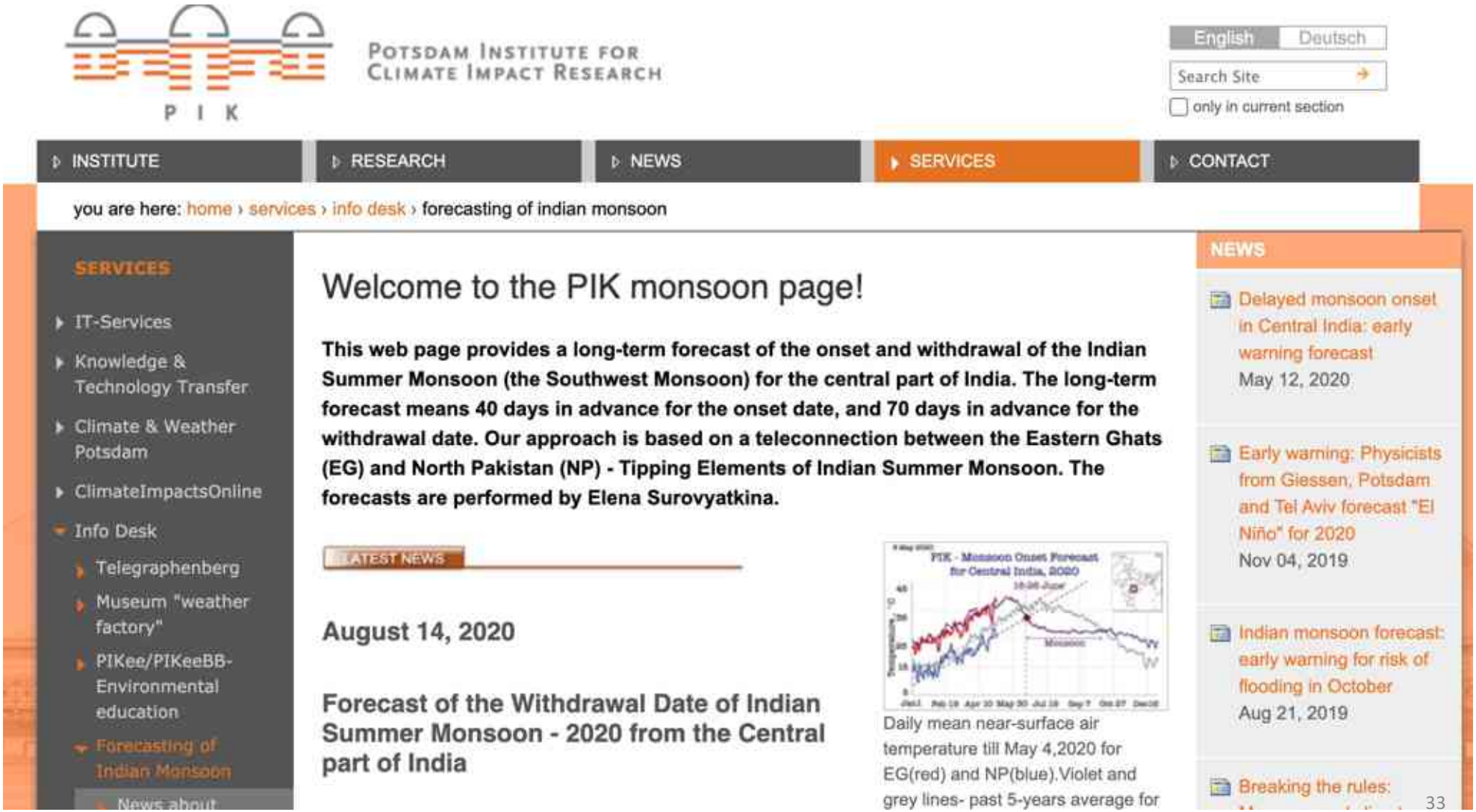
# Wet and dry seasons




NCEP/NCAR Reanalysis, 0.25 °/0.25°, 1000 hPa, 1975-2021


Central Peru: Lima, Huancavelica, Ayacucho, Ica, Junín. The square of 2.5°x2.5°, 12.5S, 75W

https://www.pik-potsdam.de/en/output/infodesk/forecasting-indian-monsoon



# German modelling to crack monsoon code

n Institute for Climate Impact Research's project, IMD kept in the loop

భద్రాచలం గోదావరి వంతెన వద్ద ప్రాజెక్టు అధికారులతో మాట్లాడుతున్న జర్మన్ ప్రొఫెసర్ కిరీన.
చిత్రంలో మంత్రులు తుమ్మల, పాల్గొన్న శ్రీ వినోద్‌కుమార్, ఈఎన్‌సీ మురళీధర్

# 10న రాష్ట్రానికి రుతుపవనాలు

(మిగతా పేజీ తరువాయి) పరిశోధనలు చేస్తున్నారని, తెలంగాణ రాష్ట్ర ప్రయోజనాల దృష్ట్యా ఇక్కడికి వచ్చి ఈ పరిశోధనా ఫలితాలను వ్యవసాయ అధికారులకు వివరించాలని కోరినట్లు ఈఎన్‌సీ మురళీధర్ తెలిపారు. భారత వాతావరణ కేంద్ర సహకారంతో పాటు పీకే సంస్థ ఇచ్చే సమాచారంతో వాతావరణ మార్పులను ముందే పసిగట్టి, ఆ మేరకు ప్రాజెక్టుల అధికారులు అప్రమత్తంగా ఉన్నారన్నారు. ఈ విషయంలో వర్షం లేదంటే వర్షం ఒక్కటి వాతావరణ పరిస్థితుల్లో గమనించిన అంశాలను పంచుకున్నారు. అటవీశాఖ మంత్రి జోగు రామన్న మాట్లాడుతూ.. తెలంగాణ ప్రభుత్వం పర్యావరణ సమతుల్యత కాపాడేందుకు పాటిస్తున్నారు. మిషన్ కాకతీయ, ఇంటింటికీ మొక్కలు, హరితహారం వంటి కార్యక్రమాలు ఇందులో భాగమేనన్నారు. ఈ కార్యక్రమంలో ఎమ్మెల్సీ చక్రపాణి పాల్గొన్నారు.

# Eastern Ghats, North Pakistan serve as tipping elements in monsoon prediction

DC CORRESPONDENT
CHENNAI JUNE 9

**The key to their research is in finding the regions where conditions for an occurrence of Indian monsoon originate**

A team of researchers led by the Potsdam Institute for Climate Impact Research (PIK) in Germany has identified two regions — the Eastern Ghats and North Pakistan — that serve as tipping elements in accurately predicting the arrival and departure of southwest monsoon.

As per their research, analysing air temperatures and relative humidity in these areas predict the arrival and departure of the monsoon earlier. "The tipping point is critical to predicting the onset of monsoon. Once it is onset, it's difficult to change," said professor Elena Surovyatkina from Russian Academy of Sciences' Space Research Institute.

"This year, we predicted as early as May 6 that monsoon will hit India on June 13 with plus or minus four days. India Meteorological Department had announced only on May 15 that monsoon will onset over Kerala on June 7," she said.

"We predicted well before 30 days when monsoon would hit central India. It will surely help the farmers in these regions. Based on our method we can predict the withdrawal of monsoon by July 15 based on the observations from the same regions," she added.

The key to their research is in finding the regions where conditions for an occurrence of Indian monsoon originate.

"We can see a pattern before the onset of monsoon. We use the precursors not to predict the time but to predict places where the critical transition originates. We take air surface temperature and calculate fluctuations."

"We applied our method for data from 1967 to 2015. Our prediction about the onset of monsoon was 74 per cent successful and withdrawal of monsoon 94 per cent correct. Even for El Nino years our predictions were nearly 65 per cent correct," she said.

When asked whether they had discussions with the IMD about using their new

# తెలంగాణలో రుతురాగం

Thu, 09 May 2019
https://epaper.andhrajyothy.com/c/39026871
Telangana Today

# Monsoon likely to hit TS by June 8

According to climate researcher the date of the onset of monsoon is between June 8 and 16

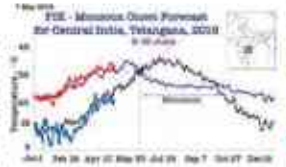
CITY BUREAU

The first monsoon showers to drench Telangana are likely to arrive between June 8 and 16, according to the monsoon forecasting model developed by scientists from Potsdam Institute of Climate Impact Research (PIK), a German government funded research institute.

Climate researcher from PIK, Prof Elena Surovyatkina, who has been issuing monsoon forecasts 40 days in advance for the central part of India in the area of Eastern Ghats since 2016, said the date of monsoon onset for Telangana is between June 8 and 16.

The German researcher pointed out that the onset of monsoons depends a lot on cyclones in the Arabian Sea and Bay of Bengal. Although the Eastern Ghats and Telangana, are neighbouring regions, there is a considerable difference in the interplay of the two branches of monsoons i.e. one from the Arabian Sea and another from the Bay of Bengal in these regions.

"Some years, the onset of monsoon appears at the same date in these two areas, while in others, it appears with a difference of 5 to10 days. Such a difference might be caused by the simultaneous appearance of two cyclones in the Arabian Sea and in the Bay of Bengal, which prevent the advance of monsoon for several days. Another reason might be an anticyclone on the north of the Arabian Sea, which decelerates the turning of the monsoon winds in the Bay of Bengal toward Indian subcontinent," Prof Elena said.




We are collaborating with IMD and our forecasts complement each other

— ELENA SUROVYATKINA,

These synoptic events are impossible to predict well in advance and it could be forecasted near the date of its appearance only and that's why the forecast in Telangana region is challenging, she said.

"Indian Meteorological Department (IMD) tracks cyclones perfectly that helps the update a monsoon onset date in June. We are collaborating with IMD and our forecasts complement each other. We are working together to improve climate resilience by building new capacities via the early forecast of monsoon," she said.

Prof Elena is part of the International Climate Initiative that is supported by German Federal Ministry for Environment and Nature Conservation aimed at building Climate Capacities in India with Telangana as a case study, which was launched in PIK. The Chairman for Indo-German Climate Research Project is TRS MLA from Yemulwada, Ramesh Chennamaneni.

Gulf Times
Thursday, April 21, 2016 | 21

INDIA |

# Germans develop new method to predict India's monsoon

AFP
Berlin

Climate researchers in Germany said yesterday they had found a way to more accurately predict the Indian monsoon, which could help maximise the subcontinent's food and hydro-power supplies.

Improved forecasts of when the heavy summer rains start and end could help millions of farmers plant crops at the right time, and allow energy providers to estimate when dams and reservoirs fill up, they said.

Global warming already affects monsoon stability and will make accurate forecasting even more important, as deviations can spark droughts and floods, said the Potsdam Institute for Climate Impact Research (PIK).

"The timing of Indian summer monsoons, on which the livelihoods of many millions of people depend, is likely becoming more erratic," said project leader Jurgen Kurths. "This makes early and accurate forecasting ever more crucial."

The scientists said they had developed a novel prediction method based on a network analysis of regional weather data, and would propose their model to the Indian Meteorological Department.

"We can predict the beginning of the Indian monsoon two weeks earlier, and the end of it even six weeks earlier than before - which is quite a breakthrough, given that for the farmers, every day counts," said Veronika Stolbova of PIK and Zurich University.

"We found that in North Pakistan and the Eastern Ghats, a mountain range close to the Indian Ocean, changes of temperatures and humidity mark a critical transition to monsoon," said Stolbova in a statement.

Usually the focus has been on Kerala region, said Stolbova, lead author of the study published in the scientific journal the Geophysical Research Letters.

The team said it used an advanced mathematical approach called network analysis of complex non-linear systems, combined with subtle statistical analyses of the early warning signals for the monsoon onset and withdrawal.

"These precursor phenomena are often buried by huge piles of weather data and hence get overlooked," said PIK guest scientist Elena Surovyatkina of the Russian Academy of Sciences' Space Research Institute.

Kurths said they had looked at the climate system "as a network, just like the social networks so many people are using in their everyday life".

"On Facebook or Twitter, you can follow how news is spreading, one posting leading to many others. In the climate system, not people but geographical regions are communicating - admittedly in a quite complex way."

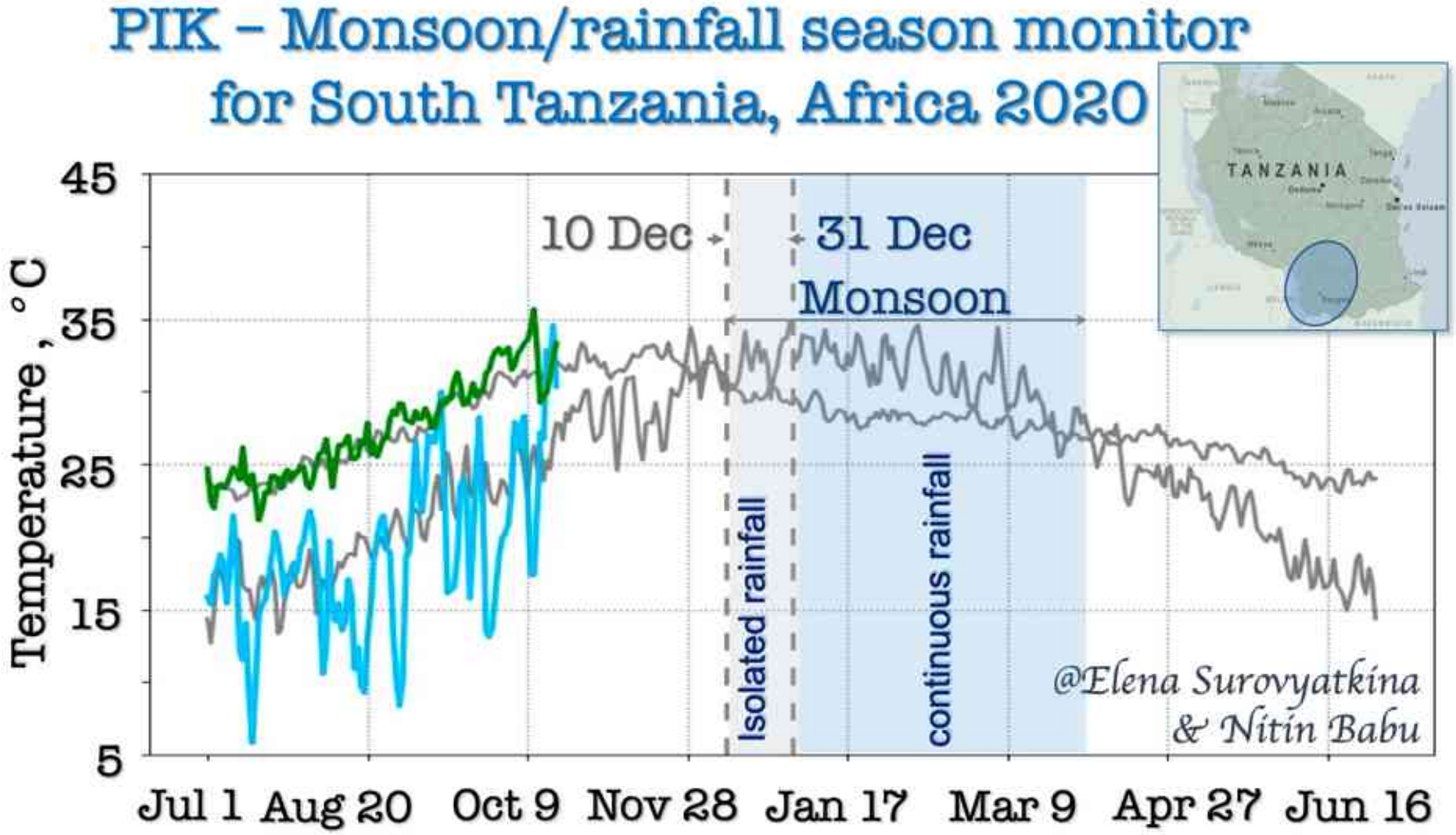
Like Facebook postings or tweets that get shared again and again, the scientists explained, temperature and humidity get transported from one place to another by atmospheric flows such as winds.

Information about monsoon timing is key for Indian farmers, who usually grow all-important crops like rice, soybean and cotton during the June-September monsoon season.

The scientists said they had tested their method with historical monsoon data and achieved correct predictions in more than 70% of cases for the start of the monsoon, and in more than 80% for its withdrawal.

The authors said their method could improve the time horizon of monsoon prediction compared to that now used in India - both during relatively normal times, and in years when the El Nino phenomenon affects the rainy season.

20 October 2020

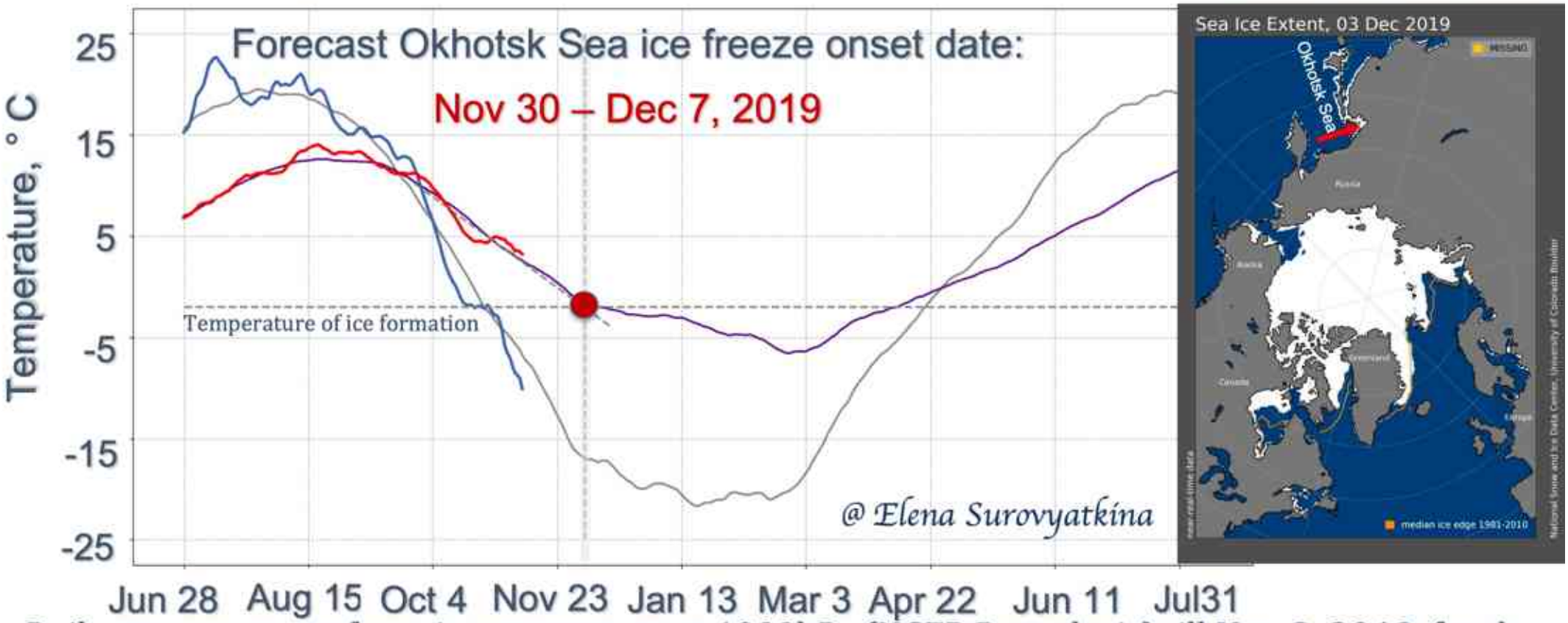



https://www.pik-potsdam.de/en/output/infodesk/forecasting-indian-monsoon

# Forecasting scheme of sea ice advance date

**Abstract ID: 20073**

Evidence from observations




Daily mean near-surface air temperature at 1000hPa (NCEP Reanalysis) till **Nov 8, 2019** for the western (red) and eastern parts (blue). Violet and gray lines - past 19-years average for same regions. The tipping point (red) indicates the critical temperature and the forecasted onset date.

# Current Progress:

I offer the following forecasts both
in North and South hemispheres:

- in India: summer monsoon in Central India and Telangana state;
- in Africa: a rainfall season in Tanzania
- in Russia and Japan Sea Ice Season in the Sea of Okhotsk.

# Possible Extensions:

- Eurasia: South Asia, South China, Japan, the Arctic Circle;
- Africa: Ethiopia, Congo;
- South and North America.

# Conclusion

The new methodology offers the following advances:

1. Predicting the date of the upcoming monsoon onset for 40 days in advance, that is unprecedently early.
2. Forecasting withdrawal date for 70 days in advance, and it is the only one available withdrawal forecast in India.
3. The applicability of the methodology is not limited by specific location; it works for different parts of India, Africa and South America.

The six years tests (2016-2021) show successful results.

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Thanks my co-authors